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connection with Application No. PQ 1655 for a patent by THE UNIVERSITY  
OF SYDNEY filed on 15 July 1999.

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**PROVISIONAL SPECIFICATION**

**Applicant(s) :**

THE UNIVERSITY OF SYDNEY

**Invention Title:**

OPTICAL PROCESSING METHOD AND APPARATUS AND PRODUCTS  
THEREOF

The invention is described in the following statement:

## OPTICAL PROCESSING METHOD AND APPARATUS AND PRODUCTS

### Field of the Invention

The present invention relates to the field of formation of optical devices and, in particular, discloses  
5 the formation of novel devices in photosensitive waveguides.

### Background of the Invention

The utilisation of optical devices in society has a high level of importance. Firstly, the transmission of  
10 data by optical fibres is an extremely important activity and often relies upon the formation of unique optical devices such as gratings structures to filter and process optical signals. Further, optical sensing also often  
15 relies upon grating devices to sense the presence of various physical conditions.

### Summary of Invention

At least preferred embodiments of the present invention provide for a method of construction of a unique optical grating structure and various devices which utilise the  
20 benefits of the structure.

In accordance with a first aspect of the present invention, there is provided a method of forming a grating comprising the steps of: dividing an input coherent beam into three coherent beams; transmitting the beams through  
25 an optical circuit so that they interfere at a first predetermined position; placing a photosensitive waveguide at the first predetermined position so as to form a grating at the predetermined position.

In one embodiment, the formed grating comprises a  
30 grating having a non-sinusoidal profile along a light propagation direction of the wave guide.

The grating may comprise a first order grating. Alternatively, the grating may comprise a higher order grating.

In one embodiment, the grating comprises a hybrid of different order gratings. Preferably, the grating comprises a hybrid of first and second order gratings.

5 In one embodiment, the step of dividing the beam comprises diffraction of the beam.

Advantageously, the three coherent beams are made up from two first order diffracted beams and one zero order diffracted beam.

10 Preferably, the transmission step further can comprise the step of: modulating the amount of one of the three beams relative to the other two beams that can be transmitted to the first predetermined position.

15 The optical circuit preferably can include at least two reflective elements for reflecting two of the beams so as to spatially locate them at the predetermined position.

The transmitting step further can comprise modulating the phase or magnitude of two of the beams interfering at the first predetermined position.

20 In accordance with a further aspect of the present invention, there is provided a method of forming a grating comprising the steps of: dividing an input coherent beam into two  $n$ th order beams and a zero order beam utilizing a phase mask, wherein  $n$ th is equal to or greater than first; placing a photosensitive waveguide substantially adjacent a surface of the phase mask where the  $n$ th order beams and the zero order beam overlap; modulating the amount of zero order beam transmitted by the phase mask to form the grating in the waveguide.

30 In one embodiment, the formed grating comprises a grating having a non-sinusoidal profile along a light propagation direction of the wave guide.

The grating may comprise a first order grating. Alternatively, the grating may comprise a higher order grating.

In one embodiment, the grating comprises a hybrid of different order gratings. Preferably, the grating comprises a hybrid of first and second order gratings.

In accordance with a further aspect of the present invention, there is provided an apparatus for creating a grating comprising: means for dividing an input coherent light beam into at least three coherent beams; an optical circuit for transmitting each of the beams to a first predetermined position so as to form a second order interference pattern at the first predetermined position for, in use, creating the grating in photosensitive waveguide.

The apparatus preferably also includes at least one modulation means for modulating the phase or magnitude of one of the beams relative to the others.

In one embodiment, the means for dividing the input beam comprises diffraction means.

Advantageously, the three beams can include the zero order diffraction and two first order diffraction beams.

An extended grating structure can be formed in the photosensitive waveguide through displacement of the waveguide relative to the diffraction means.

Relative amounts of first and second order gratings can be varied by varying the intensity of one or more of the three beams.

A profile of the grating can be made non-sinusoidal by adjusting the relative magnitude of one of the beams relative to the others.

Preferably, the profile of the grating can be made non-sinusoidal by adjusting the relative magnitude of a centre beam, being the centre beam with respect to the transmitting of the three beams to the first predetermined position, relative to the others.

In accordance with a further aspect of the present invention, there is provided an optical filter comprising: a grating structure comprising a second order grating

formed within an optical waveguide, the grating structure having a predetermined second order modulation so as to provide for predetermined filtering characteristics.

The second order modulation preferably results in the  
5 emission of filtered light energy substantially perpendicular to a core axis of the waveguide.

The filter can comprise a chirped second order grating which transmits predetermined wavelengths of light energy substantially perpendicular to a core axis of the waveguide  
10 and predetermined positions along the waveguide.

In one embodiment, the grating structure comprises a hybrid grating comprising a first order grating and the second order grating.

In one application, the filter can be utilized in a  
15 spectrographic device. In another application, the waveguide can comprise a distributed feed back laser or distributed Bragg reflectance laser and the filtered light energy forms the emission from the laser. In a further application, the second order grating structure can  
20 comprise a series of separate spaced apart second order gratings. In a further application, the grating structure can be formed with a spatially varying amount of zero order modulation along its length.

In accordance with a further aspect of the present  
25 invention, there is provided an optical free space coupler comprising: a first grating structure formed within a first optical waveguide and providing the emission of filtered light energy substantially perpendicular to a core axis of the first waveguide; a second grating structure formed  
30 within a second optical waveguide placed in the path of emission of the filtered light energy and coupling a portion of the filtered light energy along the second optical waveguide, wherein at least one of the first or second grating structures comprises a second order grating.

35 The coupler can be used as a sensor when a sample volume is used through which the filtered light energy

passes before coupling with the second second order grating. Portions of the first waveguide or the second waveguide are preferably coated with a reflective material which concentrates the filtered light energy along a  
5 predetermined path of transmission from the first second order grating to the second second order grating.

In one embodiment, at least one of the first or second grating structures comprises a hybrid of a first order grating and a second order grating.

10 In accordance with a further aspect of the present invention, there is provided an optical sensor comprising: a grating structure comprising a second order grating formed within an optical waveguide, the grating structure having a predetermined second order modulation so as to  
15 provide for the reciprocal emission of optical energy substantially perpendicular to the optical waveguide; an optically sensitive material spaced adjacent to the optical waveguide, the material having optical reflective properties variable in accordance with an external physical  
20 parameter, the material reflecting the emitted optical energy from the grating structure back to the grating structure.

In one embodiment, the grating structure comprises a first order grating and the second order grating.

25 In the aforementioned arrangements, the grating structure can be formed offset from a central axis of the optical waveguide so as to provide directional perpendicular emission. Furthermore, it will be appreciated by a person skilled in the art that other  
30 higher order grating structures (i.e. higher than second order) may be utilised. In the description of preferred embodiments given below, calculations are presented for second order gratings (and hybrid gratings formed from first order and second order gratings). It will be  
35 appreciated that similar calculations can be performed for higher order gratings, however, it is noted that the loss



characteristics will vary between different higher order gratings. E.g. the angular directionality of the loss will differ.

5 The grating structure can be formed with a spatially varying amount of zero order modulation along its length.

In accordance with a further aspect of the present invention, there is provided a grating structure for an optical fibre, the grating structure comprising a higher order grating for providing an optical loss mechanism.

10 Preferably, the grating structure comprises a second order grating.

Preferably, the grating structure comprises a hybrid of a first order grating and the second order grating.

15 In accordance with another aspect of the present invention, there is provided a method for suppressing ripples in a dispersion compensator in an optical fibre, the method comprising the step of utilising an optical loss mechanism to suppress the ripples.

20 Preferably, the optical loss mechanism comprises optical loss in a grating structure which comprises a higher order grating.

Advantageously, the grating structure comprises a second order grating. The grating structure may comprise a hybrid of a first order grating and a second order grating.

25 In another embodiment, the optical loss mechanism comprises absorption in an absorbing material in the fibre.

In accordance with another aspect of the present invention, there is provided a dispersion compensator for compensating dispersion in an optical fibre, the  
30 compensator comprising means for providing an optical loss mechanism for suppressing ripples.

Preferably, the means for providing an optical loss mechanism comprise a grating structure comprising a higher order grating.

Advantageously, the grating structure comprises a second order grating. The grating structure may comprise a hybrid of a first order grating and a second order grating.

In one embodiment, the optical loss mechanism  
5 comprises absorption in an absorbing material in the fibre.

#### Brief Description of the Drawings

Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only,  
10 with reference to the accompanying drawings in which:

Fig. 1 is a schematic illustration of the operation of a second order grating;

Fig. 2 illustrates a first grating writing system for writing second order gratings;

15 Fig. 3 illustrates a second possible grating writing system for writing second order gratings;

Fig. 4 is an intensity graph having different zero orders;

Fig. 5 illustrates the perpendicular radiation modes  
20 for a second order grating;

Fig. 6 illustrates a series of graphs showing amplifier gain manipulation through filtering;

Fig. 7 is a schematic illustration of an example application of a second order grating;

25 Fig. 8 is another example illustration of an application of a second order grating;

Fig. 9 illustrates a further application of a chirped second order grating;

30 Figs 10 and 11 illustrate a laser application of a second order grating;

Fig. 12 illustrates a further application of a second order grating;

Fig. 13 illustrates the utilisation of second order gratings for waveguide coupling.

35 Fig. 14 illustrates a second order grating application to distribute emissions;

Fig. 15 illustrates the process of writing a second order grating on one side of a waveguide;

Figs 16 and 17 illustrate a sensing application of second order gratings;

5 Figs 18 and 19 illustrate an alternative sensor application;

Fig. 20 illustrates a further application of second order gratings;

10 Fig. 21 illustrates the alteration of zero order component in a grating structure.

#### Description of the preferred and other embodiments

In the preferred embodiments, there are disclosed unique processors for the creation of a new form of Bragg grating structure which allows for the emission of optical  
15 energy substantially perpendicular to the grating structure. Methods of construction of such gratings are disclosed in addition to a number of possible utilisation of such device.

In the preferred embodiment, a grating structure is  
20 created which allows for the emission of optical energy substantially perpendicular to the grating structure. This is provided through the utilisation of high order coupling to radiation modes out of the gratings.

Turning initially to Fig. 1, there is illustrated an  
25 optical fibre 1 having a grating structure 2 with light being transmitted along the core 3 of the fibre and the grating 2 reflecting a portion of the light in addition to transmitting a portion 5 in a perpendicular direction.

A guided light wave travelling along the fibre 3 with  
30 a propagation constant  $\beta_g$  will interact with the Fourier components of the grating 2 to excite radiation modes with propagation constant  $\beta_r \approx \text{Re}(\beta_g) - 2\pi p/\Lambda$  ( $p = \pm 1, \pm 2, \dots$ ) where  $\Lambda$  is the grating period. Radiation modes with propagation constant  $\beta_r$  only exist if  $|\beta_r| < 2\pi n_2/\lambda$ , where  $\lambda$   
35 is the free space wavelength and  $n_2$  is the cladding index of the fibre 1. Therefore, in a first-order grating with

$\text{Re}(\beta_g) \approx \pi/\Lambda$  and  $2\pi n_2/\lambda < \text{Re}(\beta_g) < 2\pi n_1/\lambda$ , no radiation modes can be excited. However, for blazed gratings and higher order gratings this is no longer the case. Blaze is readily removed with accurate alignment in most writing  
5 setups and is therefore not a major consideration. On the other hand, for a second order grating,  $\text{Re}(\beta_g) \approx 2\pi/\Lambda$ . This means that for  $p = \pm 1$  the guided mode propagating both backwards and forwards in the grating will couple with radiation modes for which  $\beta_r \approx 0$ . For a radiation mode  
10 with propagation constant  $\beta_r$ , the radiation angle in the cladding layer is given by:

$$\theta = \arccos \left[ \frac{\beta_r}{(2\pi n_2 / \lambda)} \right] \quad (\text{Eq. 1})$$

The radiation angle in the second order grating is therefore  $90^\circ$  and first-order radiation loss will occur.  
15 Strong directionality is expected. The amount of loss will be dependent on a number of factors including index modulation, index modulation profile and penetration of UV-induced index change across the waveguide core which determines the intensity profile of radiation loss around  
20 the waveguide - analogous to the behaviour predicted with different tooth-shaped index profiles in semiconductor radiation-coupled gratings and also previously experimentally observed in fibre gratings. The presence of a 2nd order grating therefore can lead to significant light  
25 coupled out of the side of a Bragg grating.

In one embodiment of the invention, second order gratings can be constructed through the utilisation of the zero order diffraction mode when writing the grating.

A number of different techniques for utilising the  
30 zero order are possible. In one embodiment, a three or more beam interference arrangement as schematically illustrated in Fig. 2 can be used. An initial coherent beam 10 is being projected through a phase mask 11 so that three beams including a zero order beam 12 and two first

order beams 13, 14 are output. The two beams 13, 14 are reflected by a mirror 15, 16 so as to interfere at point 17 so as to produce an interference pattern. A photosensitive fibre 18 is placed at this point such that the interference pattern is imprinted in the fibre, normally by way of reflective index variation in accordance with the interference pattern. In the preferred embodiment, the zero order beam 12 is also projected onto the fibre at the same point 17 so as to provide for a second order grating to form a hybrid grating comprising first and second order gratings. Preferably, an attenuator 21 and phase modulation or attenuation elements 20, 22 are provided so as to control the amount of the zero order relative to the first order in addition to controlling the phase of the pattern formed on the optical fibre 18. In this manner, chirping and other effects can be produced in addition to a controlled mixing of the amount of the zero order beam.

Other arrangements are possible which control the amount of zero order beam. For example, in Fig. 3, there is illustrated schematically a "direct writing" system wherein a phase mask 30 is provided and a fibre 31 is placed behind the phase mask. A coherent UV beam 32 is swept along the phase mask which produces a first order interfering beam 34, 35 in addition to a zero order beam 36. In the arrangement of Fig. 3 varying the depth of the phase mask 30 can be used to alter the amount of zero order beam.

Hence, in the preferred embodiments, a super structure grating of both first and second order periodicities is formed utilising the zero order and first order beams.

The basic premise in the mechanism arises from significant zero order interaction with the +1 and -1 diffraction orders of a phase mask. The angle of each diffracted beam,  $\theta_m$ , can be calculated from the expression for monochromatic light incident on a diffraction grating:

$$\sin \theta_n = \sin \theta_i + m \frac{\lambda}{\Lambda} \quad (\text{Eq. 2})$$

where  $\theta_i$  is the angle of the incident beam ( $0^\circ$  when normal to the diffraction grating),  $m$  is the diffraction order,  $\lambda$  is the writing wavelength, and  $\Lambda$  is the phase mask period.

5 Using the appropriate angles, the period is  $\Lambda_{m,n} = \lambda / \sin(\theta_{m,n})$ , where  $\theta_{m,n}$  is the angle between the two orders. This expression is similarly derived to that in equation (1). To determine this amplitude the intensity can be calculated by squaring the sum of the real and complex components of  
10 the individual amplitudes,  $a_N$ , where  $N$  is the diffraction order of the phase mask:

$$I = |a_0 \exp(jkx \sin \theta_0) + a_1 \exp(jkx \sin \theta_1) + a_{-1} \exp(jkx \sin \theta_{-1})|^{-2} \quad (\text{Eq. 3})$$

The angular quantity,  $\theta_N$ , which determines the phase of each wave, is obtained from

$$15 \quad \theta_n = \sin^{-1} \left( \frac{N\lambda}{nd} \right) \quad (\text{Eq. 4})$$

where  $d$  is the phase mask period (specified in experiments as  $1.064 \mu\text{m}$ ). The above formulation calculates the electric field distribution immediately after the phase mask. This is suitable for direct contact printing of gratings on rib  
20 waveguides but in most instances an additional term in the amplitude of each wave is required for buried waveguides and optical fibres where the core is at a distance from the phase mask determined by a cladding. Talbot planes away from the phase mask surface, which can have a period with  
25 dimensions less than the waveguide, are neglected.

Fig. 4 shows the calculated intensity distribution arising from the interactions between the 0, +1, and -1 orders for varying amounts of zero order. Assuming most of the incoming light is in these orders the intensity at the  
30 peaks of the interference between these orders will always be substantially larger than the intensity of the incoming light. Notably, even when the zero order is only 1% of the input light a substantial peak intensity maximum occurs

every  $1\mu\text{m}$ . Since the phenomenological growth of index with UV is often not linear, this disparity can be much larger when examining the generated index profile. Fig. 5 is a schematic of such a small complex grating with a small amount diffracted light coupling to radiation modes with  $\beta_r = 0$ .

As a consequence of this superposition of the interference between the zero order and the +1 and -1 orders, there exists a component of a 2nd order grating. Diffraction at the Bragg wavelength of the first order grating occurs at ninety degrees at those wavelengths satisfying the criterion of twice the pitch of the Bragg grating; i.e.

$\Lambda_{2\text{nd}} = \Lambda_B / N - 2\Lambda_B$ . The relative intensity depends on the ratio of the peak index amplitude of the 2nd order grating with that of the Bragg grating:  $\Delta n_{2\text{nd}} / \Delta n_B$ . To quantify the expected losses systematic and careful measurements of a number of parameters, including grating growth curves and the intensities of diffracted phase mask orders, is required. However, the losses in these complex combination gratings superstructures will always be less than that of a strong pure second order grating that can couple up to 3dB of its light to radiation modes orthogonal to the grating axis.

The second ordered grating structure can therefore be utilised in a number of ways in different photonics devices through appropriate control of the zero order component of any beam. Various devices will be discussed herein after under separate headings.

### Filters

Often, it is necessary to provide for filtering of optical signals. In one particularly common case is the gain flattening of, for example, Erbium doped fibres. The gain of an Erbium doped fibre tends to vary with wavelength and is shown schematically in Fig. 6. It is obviously desirable to provide for the same level of gain across a

wide bandwidth. It is also desirable to provide a variable filter such that the gain is substantially constant 41 across a wavelength. Such a filter can be constructed as illustrated in Fig. 7 wherein a second order grating 45 is  
5 formed in a fibre 46. The grating 45 can be a chirped grating having predetermined reflectance criteria at different frequencies. The grating is also modulated by a zeroth order beam so as to radiate e.g. 47 variable mounts of light with the degree of radiation of the beam being  
10 higher when high levels of gain are present at the particular wavelength. In this manner, a combination of first and second order grating structures can be written so as to radiate energy and therefore provide for gain flattening. The resulting output 48 is a gain flattened  
15 narrow band response. The arrangement of Fig. 7 can also be configured to operate in a transmission mode. Advantageously, it has low sensitivity to cladding mode variations.

#### Spectrometers

20 The principle of Fig. 7 can be extended to the construction of a spectrometer type device. Such an arrangement is illustrated in Fig. 8 wherein a chirped grating 50 is provided having both first and second order grating structures. Hence, different wavelengths e.g. 51,  
25 52, 53 will be emitted in a perpendicular direction depending on the periodicity of the chirp. The arrangement of Fig. 8 can hence be utilised in spectrometric analysis or in wavelength division multiplexing filters. The arrangement of Fig. 8 can be extended to a planar waveguide  
30 form as illustrated in Fig. 9 wherein a wave guide 60 contains a chirped grating structure 61 which emits wavelengths  $\lambda_1$ ,  $\lambda_2$ ,  $\lambda_3$ .. Three collectors 63 - 65 are provided for collecting the emitted light which can be forwarded for analysis. Hence, the input light 66 will be  
35 divided into its wavelength channels.

#### Surface emitting gratings



The construction of hybrid grating structures can be extended to the formation of surface emitting grating structure for use in lasers etc. An initial example of an arrangement is as illustrated in Fig. 10 wherein a laser structure 70 is provided with distributed Bragg reflectors 71, 72. A pump input causes the intermediate portion 74 to lase and a second order grating 75 of the hybrid grating structure 77 is provided for the emission 76 of the laser light, whilst the first order grating 72 of the hybrid grating structure 77 reflects.

Fig. 11 illustrates an alternative arrangement wherein a separate hybrid grating structure 80 is provided for laser emission. The arrangement of Figs 10 and 11 can be extended to a distributed feedback (DFB) laser with the second order grating providing an interruption of the degeneracy of side mode. This allows for a large area pump lasers for integrated optics with easy coupling and high powers.

The hybrid grating structure can be utilised as illustrated in Fig. 12, as enlarged area "semi-coherent" emitter for utilisation as a sensor source etc.

#### Free Space Couplers

The utilisation of second order gratings can be extended to providing for free space coupling. A suitable arrangement as illustrated in Fig. 13 where it is desired to couple input light 81 transmitted along fibre 82 to a planar waveguide structure 84 having internal waveguide 83. A second order grating 86 is constructed in one end of the fibre 82 which also contains a reflective coating 87. The reflective coating reflects the light outputted perpendicular to the fibre 82 down to the waveguide 83 wherein a further second order grating 88 is formed. The grating 88 couples with the emitted light via the principle of reciprocity into the waveguide where it is output 83.

#### Control of Beam Divergence for Filters, Lasers, etc.

The principle of hybrid grating structures can be extended as illustrated in Fig. 14 to provide for a larger effective aperture through the utilisation of multiple second order gratings e.g. 90 - 94. A larger aperture or  
5 extended grating structure means less divergence and a quasi coherent output is possible from incoherent sources.

Ideally, to provide enhanced directionality, the side of transmission perpendicular to the waveguide is controlled. This can be achieved by writing gratings on  
10 one side of the waveguide. Such an arrangement is illustrated in Fig. 15 where a waveguide structure is shown 100 where light is transmitted along the waveguide 101 and a series of second order gratings e.g. 102 are provided on a first side of the waveguide 101. This results in a  
15 transmission perpendicular to the waveguide structure. This allows for complex integrated optic structures to be produced on a planar waveguide.

#### Large Areas Sensor Heads

The second order grating principle can be extended to  
20 sensor heads with an example illustrated in Fig. 16 and 17. A waveguide 110 is provided having a second order grating 111. Preferably, a reflective coating is formed around predetermined portions of the fibre 110 so as to reflect light downwards through a volume 113 which is to be  
25 sampled. A second fibre 115 is provided which couples the light travelling through the volume 113 to output 116. Again, a reflective coating 117 is also provided for enhanced coupled. Fig. 17 illustrates a sectional view through the line A - A' of Fig. 16 and more clearly  
30 illustrates the mirror portions 112, 117 which add to enhance the degree of coupling. The wavelength absorption in volume 113 will affect the spectra of output 116 which can be separately analysed to determine sensor operation.

The arrangement of Fig. 16 and Fig. 17 can be extended  
35 as shown in Fig. 18 and Fig. 19 to the provision of wavelength specific sensors. Fig. 18 illustrates a side-

view of a sensor arrangement with Fig. 19 illustrated in the corresponding sectional view taken through the line B - B' at Fig. 18. The arrangement 120 includes a second order grating 121 which transmits input light 122 in a perpendicular manner. A porous coating 123 is provided and is of a reflective type. Hence, the light reflected from the coating 123 is reflected back and coupled back by second order grating 122 where it is subsequently output 125. The reflective material 123 can be modulated to change the integrated reflection and the corresponding modulated output signal 125 returned. Alternatively, the reflective material may change properties with absorption of a species to be identified which allows for spectral analysis of the absorbed gas via variations in the output 125. A second gratings 126 is also provided for reflecting back light via the waveguide.

#### Narrow Band Attenuators

The second order grating principle can be extended to provide a novel form of attenuator. Such an arrangement is illustrated in Fig. 20, wherein a chirped grating 130 is provided which includes a second order grating having controlled degrees of radiation loss to bounce an input signal 131 so as to provide bandwidth attenuation of output signal 132.

#### 25 Tunable Narrow Bend Attenuator

The arrangement in Fig. 20 can be extended by providing a chirped grating with a chirped index modulation provided by "chirping" the degree of zero order irradiation. The amount of zero order can be varied as illustrated in Fig. 21 with grating position. Such a chirped grating structure can then be subjected to stretching, pressure or heating. As the structure is stretched the narrow band position will move across a series of desired wavelengths. Further, stretching or compressing the grating structure will alter the amount of perpendicular radiation.

### Dispersion Compensator

The principle of Fig. 20 can be extended to providing dispersion compensation wherein the grating structure 130 is written in an Erbium doped amplifying fibre or similar amplifier. The degree of radiation also can be controlled so as to provide for simultaneous dispersion compensation and radiation loss. By utilising a combination of first and second order grating structures, optimisation of the amount of loss can be achieved. The arrangement also allows for the suppression of cavity based ripples.

### Photonic Band Gap And Generation

The arrangement of Fig. 2 also allows for the formation of complex Photonic band gap structures in the interference vicinity 17. The area of interference 17 will contain a complex interference pattern which can be imprinted on a photosensitive material. Such complex arrangements can be utilised to store information for later playback. By controlling the attenuators/phase elements 20 - 22 and/or the angles of the mirrors 15, 16 arbitrary complex structures can be formed. This interference regime is analogous to the complex interference formed where Talbot & Lohmann planes are generated within the Fresnel zone just after a phase mask grating.

It would be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments and devices without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

We Claim:

1. A method of forming a grating comprising the steps of:

- dividing an input coherent beam into three coherent  
5 beams;
- transmitting the beams through an optical circuit so that they interfere at a first predetermined position;
- placing a photosensitive waveguide at the first predetermined position so as to form a grating at the  
10 predetermined position.

2. A method as claimed in claim 1 wherein the step of dividing the beam comprises diffraction of the beam.

3. A method as claimed in claim 2, wherein the three coherent beams are made up from two first order diffracted  
15 beams and one zero order diffracted beam.

4. A method as claimed in any one of the preceding claims, wherein the transmission step further comprises the step of:

- modulating the amount of one of the three beams  
20 relative to the other two beams that can be transmitted to the first predetermined position.

4. A method as claimed in any one of the preceding claims, wherein the optical circuit comprises at least two reflective elements for reflecting two of the beams so as  
25 to spatially locate them at the predetermined position.

5. A method as claimed in any one of the preceding claims, wherein the transmitting step further comprises modulating the phase or magnitude of two of the beams interfering at the first predetermined position.

30 6. A method of forming a grating comprising the steps of:

- dividing an input coherent beam into two  $n$ th order beams and a zero order beam utilizing a phase mask, wherein  $n$ th is equal to or greater than first;

- placing a photosensitive waveguide substantially adjacent a surface of the phase mask where the  $n$ th order beams and the zero order beam overlap;

- modulating the amount of zero order beam transmitted  
5 by the phase mask to form the grating in the waveguide.

7. An apparatus for creating a grating comprising:

- means for dividing an input coherent light beam into at least three coherent beams;

- an optical circuit for transmitting each of the  
10 beams to a first predetermined position so as to form a second order interference pattern at the first predetermined position for, in use, creating the grating in photosensitive waveguide, wherein the grating comprises a hybrid of first and second order gratings.

15 8. An apparatus as claimed in claim 7 further comprising at least one modulation means for modulating the phase or magnitude of one of the beams relative to the others.

20 9. An apparatus as claimed in claims 7 or 8, wherein the means for dividing the input beam comprises diffraction means.

10. An apparatus as claimed in claim 9 wherein the three beams can include the zero order diffraction and two first order diffraction beams.

25 11. An optical filter comprising:

- a grating structure comprising a second order grating formed within an optical waveguide, the grating structure having a predetermined second order modulation so as to provide for predetermined filtering characteristics.

30 12. An optical filter as claimed in claim 11 wherein the second order modulation preferably results in the emission of filtered light energy substantially perpendicular to a core axis of the waveguide.

35 13. An optical filter as claimed in claims 11 or 12 further comprising a chirped second order grating which transmits predetermined wavelengths of light energy

substantially perpendicular to a core axis of the waveguide and predetermined positions along the waveguide.

14. An optical filter as claimed in anyone of claims 11 to 13, wherein the grating structure comprises a hybrid  
5 of a first order grating and a second order grating.

15. An optical free space coupler comprising:

- a first grating structure formed within a first optical waveguide and providing the emission of filtered light energy substantially perpendicular to a core axis of  
10 the first waveguide;

- a second grating structure formed within a second optical waveguide placed in the path of emission of the filtered light energy and coupling a portion of the filtered light energy along the second optical waveguide,  
15 wherein at least one of the first or second grating structures comprises a second order grating.

16. A coupler as claimed in claim 15, wherein the at least one of the first or second grating structures comprises a hybrid of a first order grating and a second  
20 order grating.

17. A coupler as claimed in claim 15 or 16, wherein portions of the first waveguide or the second waveguide are preferably coated with a reflective material which concentrates the filtered light energy along a  
25 predetermined path of transmission from the second order grating to a second second order grating of the other grating.

18. An optical sensor comprising:

- a grating structure comprising a second order  
30 grating formed within an optical waveguide, the grating structure having a predetermined second order modulation so as to provide for the reciprocal emission of optical energy substantially perpendicular to the optical waveguide;

- an optically sensitive material spaced adjacent to  
35 the optical waveguide, the material having optical reflective properties variable in accordance with an

external physical parameter, the material reflecting the emitted optical energy from the grating structure back to the grating structure.

19. A sensor as claimed in claim 18 wherein the  
5 grating structure can be formed offset from a central axis of the optical waveguide so as to provide directional perpendicular emission.

20. A sensor as claimed in claim 19 wherein the  
grating structure can be formed with a spatially varying  
10 amount of zero order modulation along its length.

21. A sensor as claimed in anyone of claims 18 to 20, wherein the grating structure comprises a hybrid of a first order grating and a second order grating.

22. A grating structure for an optical fibre, the  
15 grating structure comprising a higher order grating for providing an optical loss mechanism.

23. A grating structure as claimed in claim 22, wherein the grating structure comprises a second order grating.

20 24. A grating as claimed in claim 23, wherein the grating structure comprises a hybrid of a first order grating and a second order grating.

25. A method for suppressing ripples in a dispersion compensator in an optical fibre, the method comprising the  
25 step of utilising an optical loss mechanism to suppress the ripples.

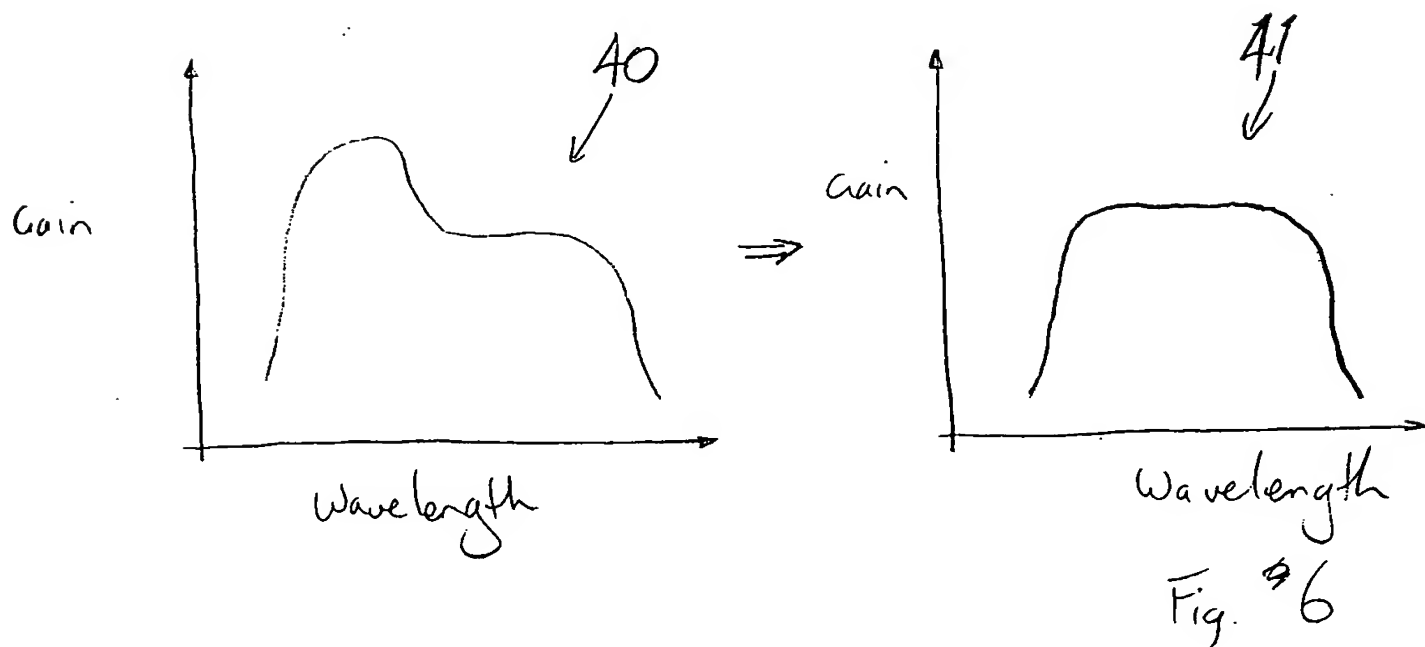
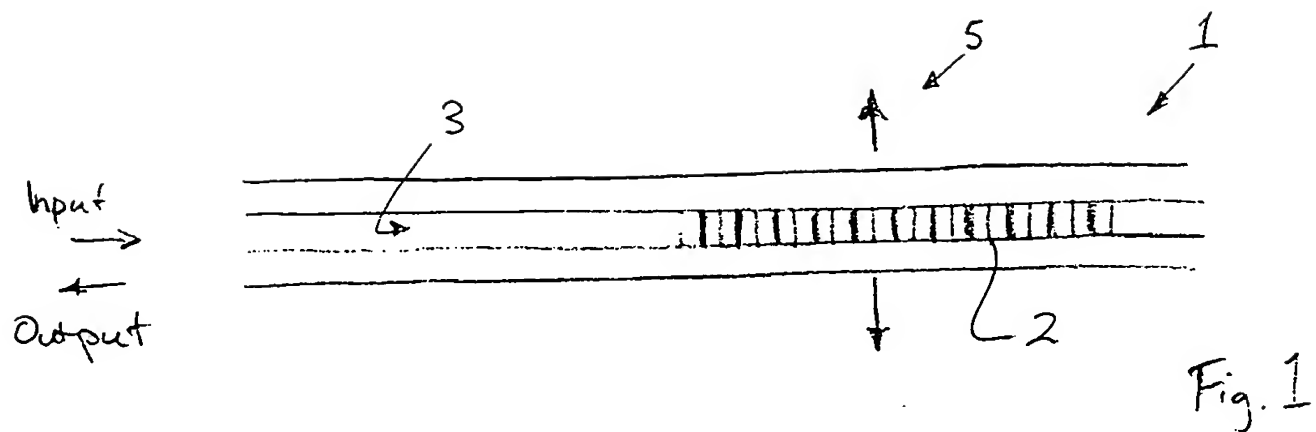
26. A method as claimed in claim 25, wherein the optical loss mechanism comprises radiation loss via a higher order grating of the optical fibre.

30 27. A dispersion compensator for compensating dispersion in an optical fibre, the compensator comprising means for providing an optical loss mechanism for suppressing ripples.

28. A compensator as claimed in claim 27, wherein the  
35 means for providing an optical loss mechanism comprises a grating structure comprising a higher order grating.



29. A compensator as claimed in claim 28, wherein the grating structure comprises a hybrid of a first order grating and a second order grating.



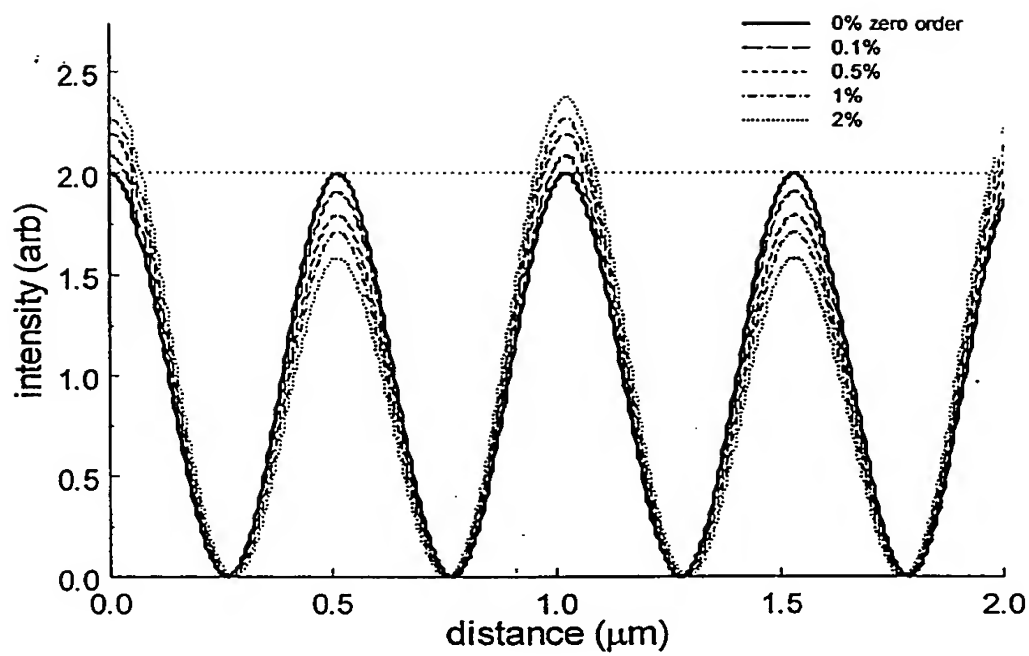
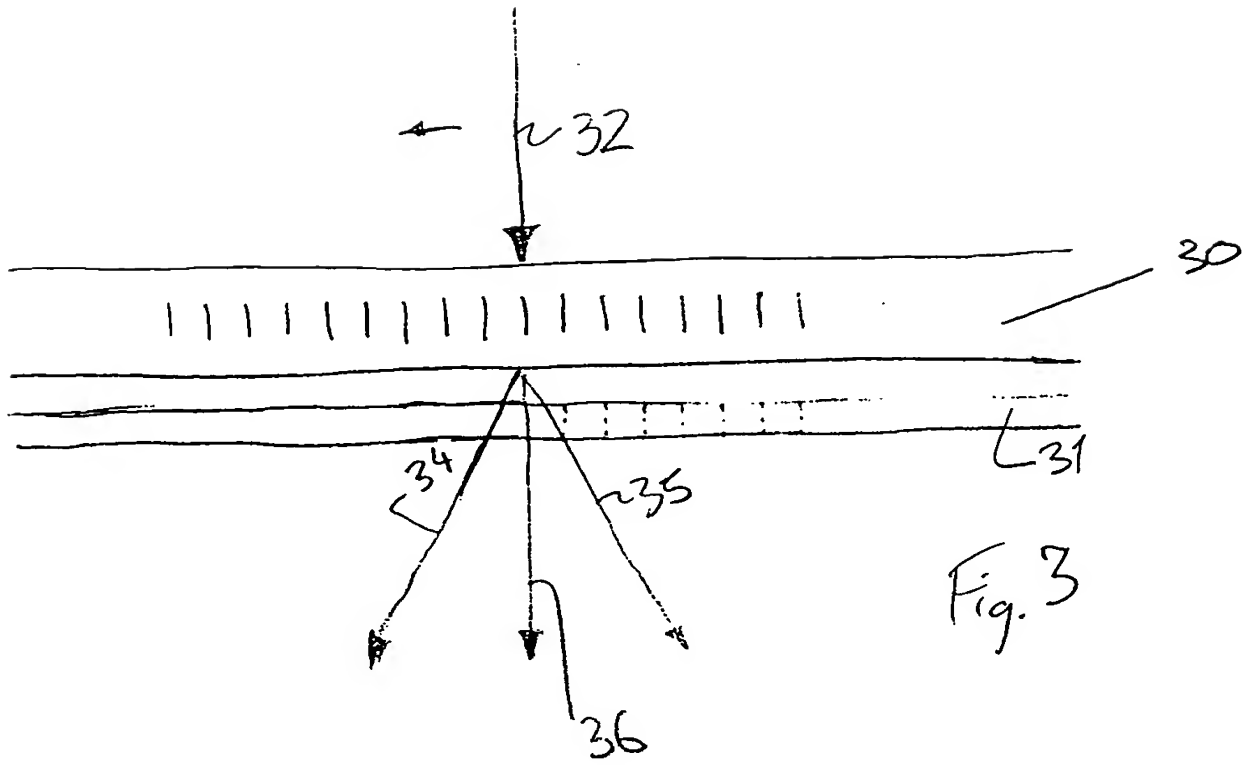


Fig. 4



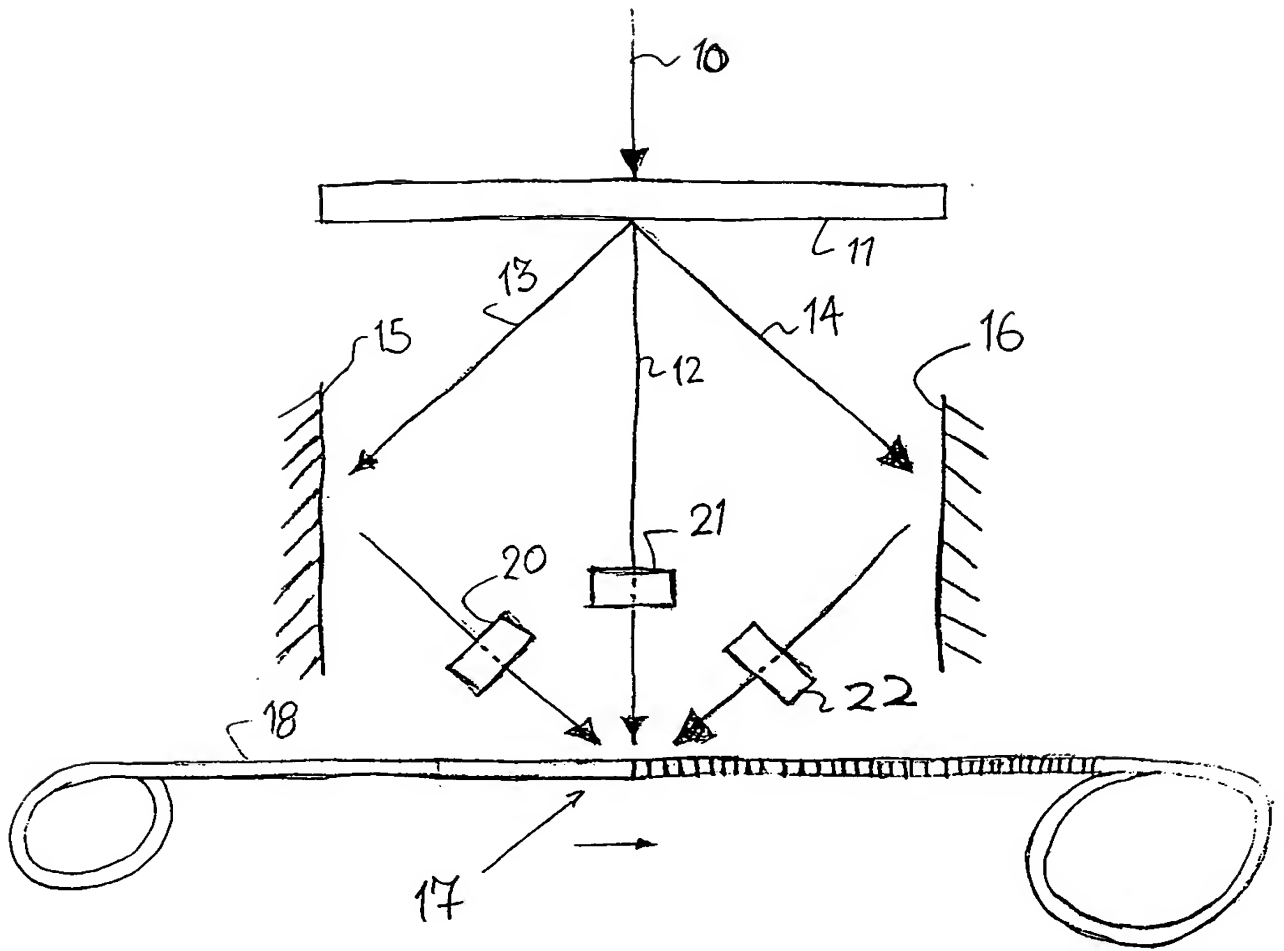
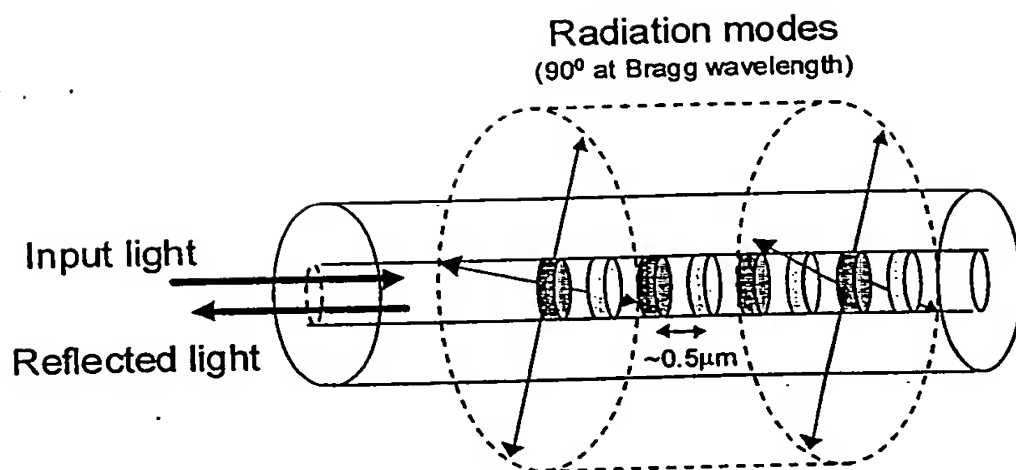
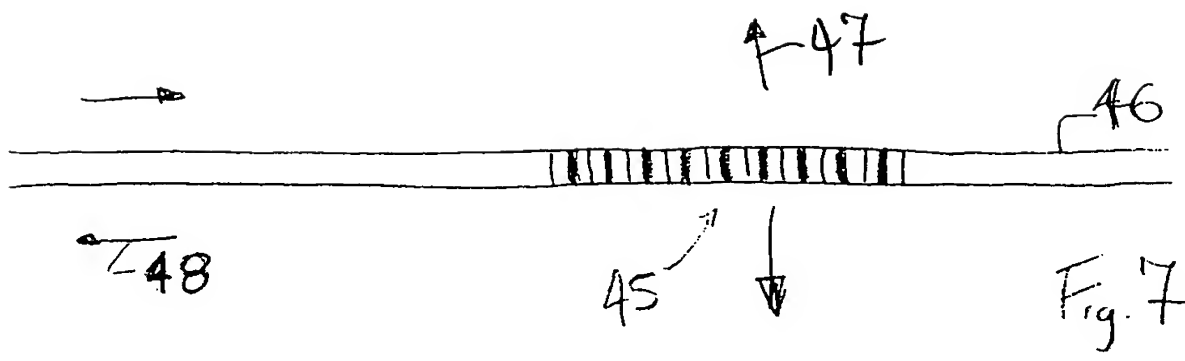
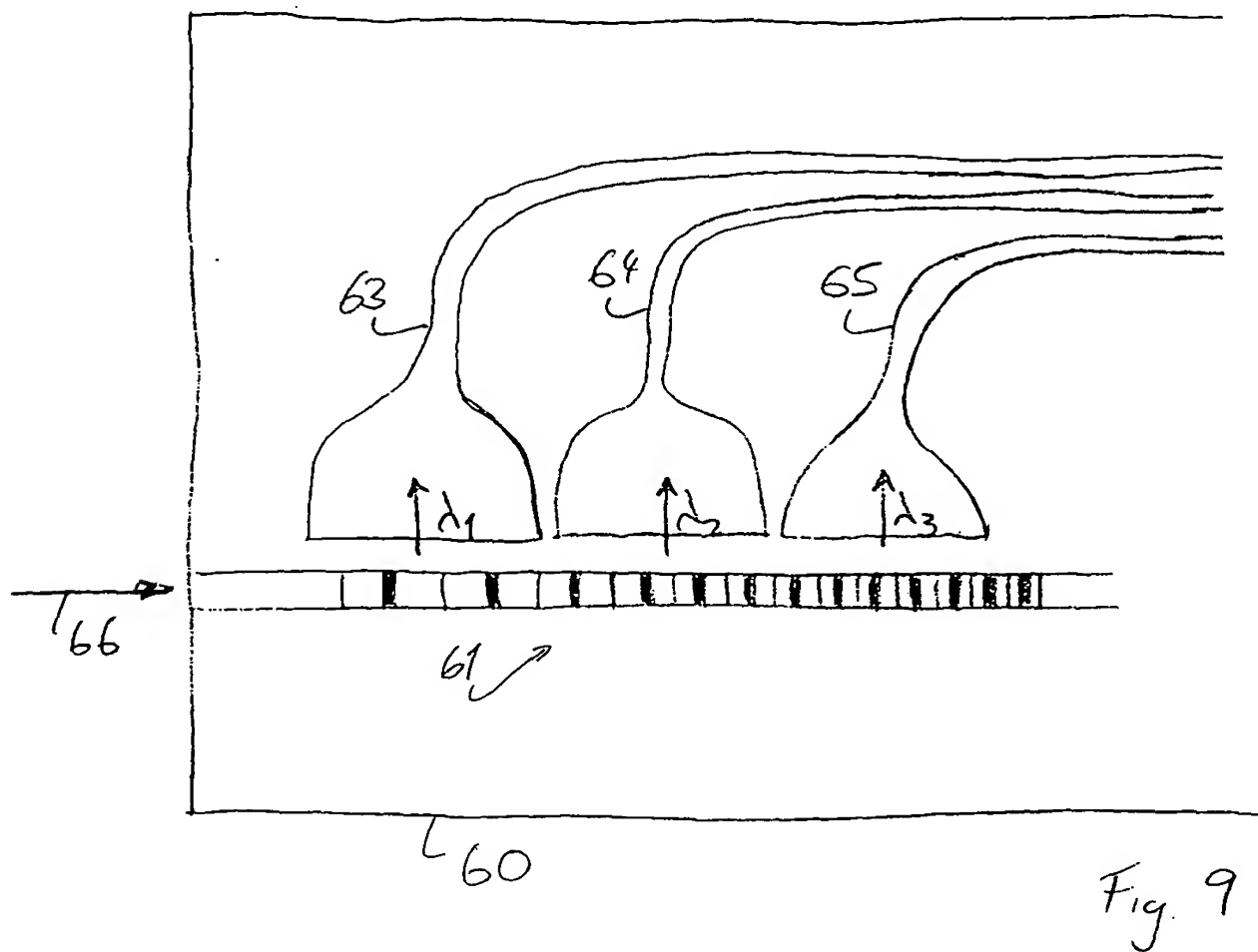
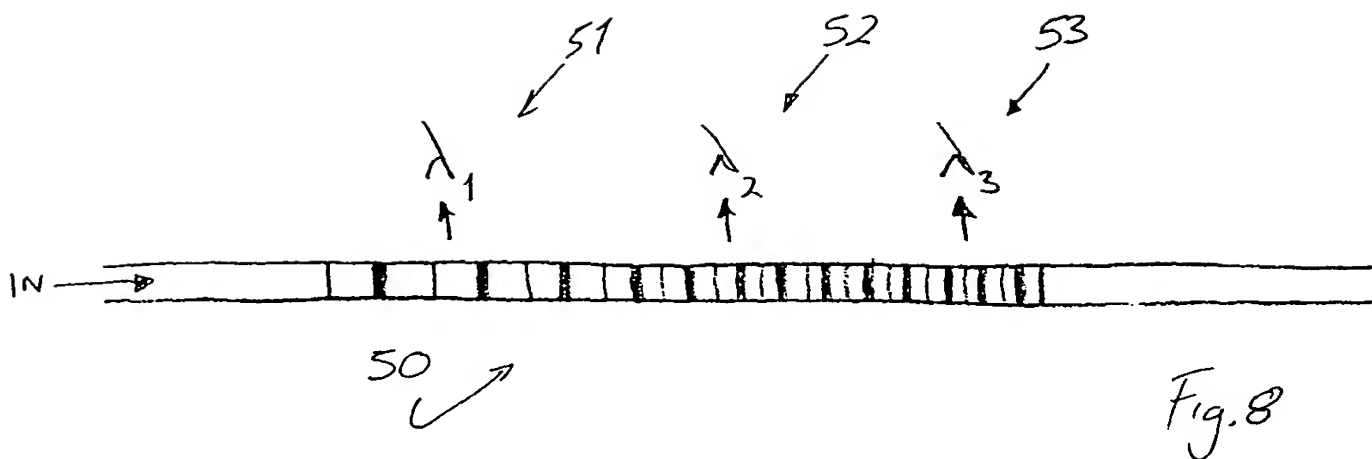


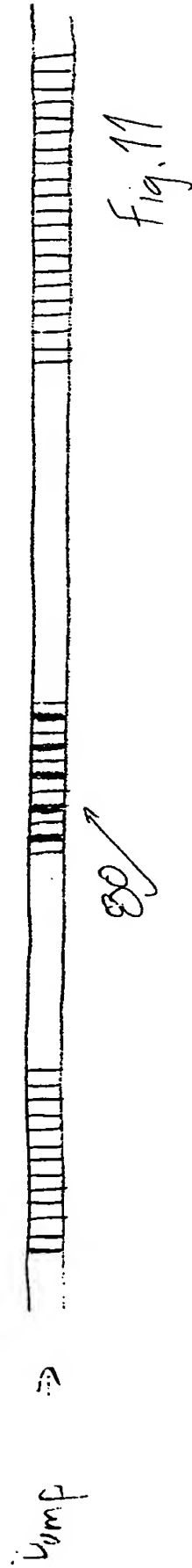
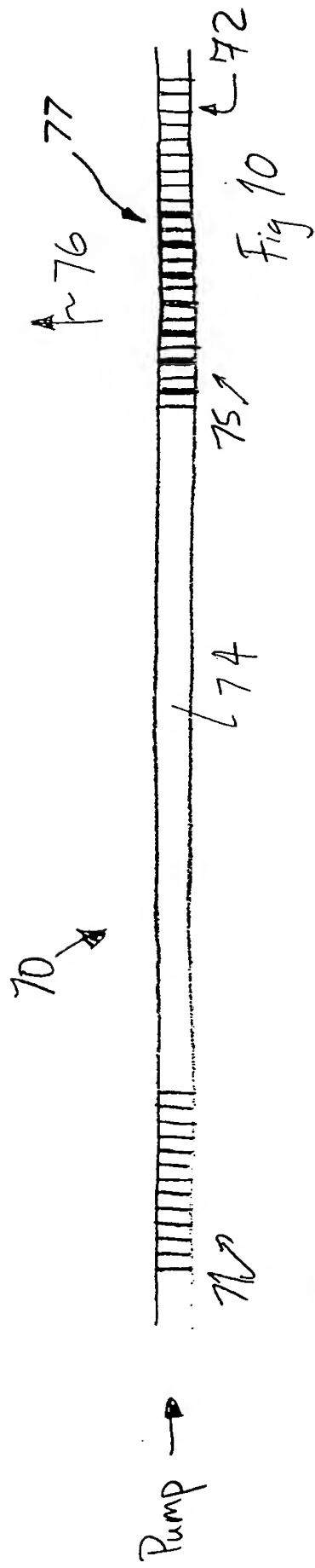
Fig. 2

*Fig. 5*









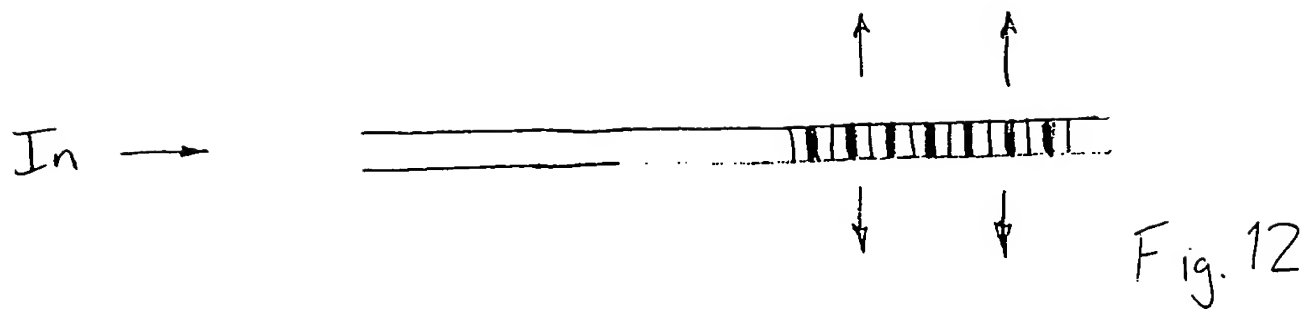


Fig. 12

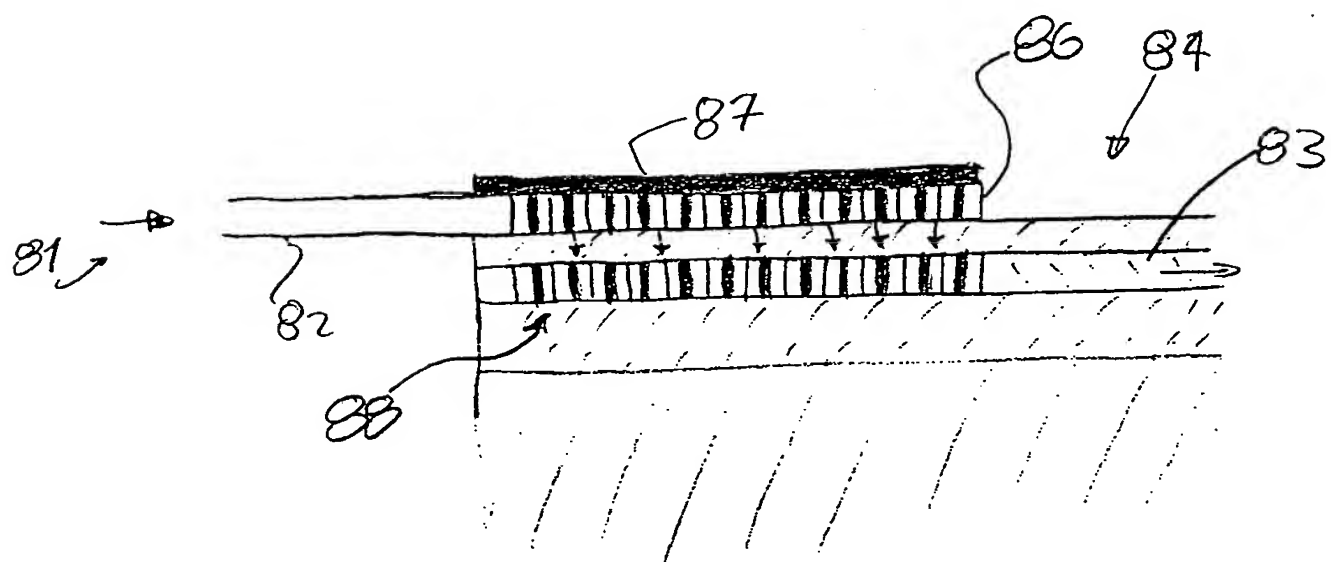


Fig. 13

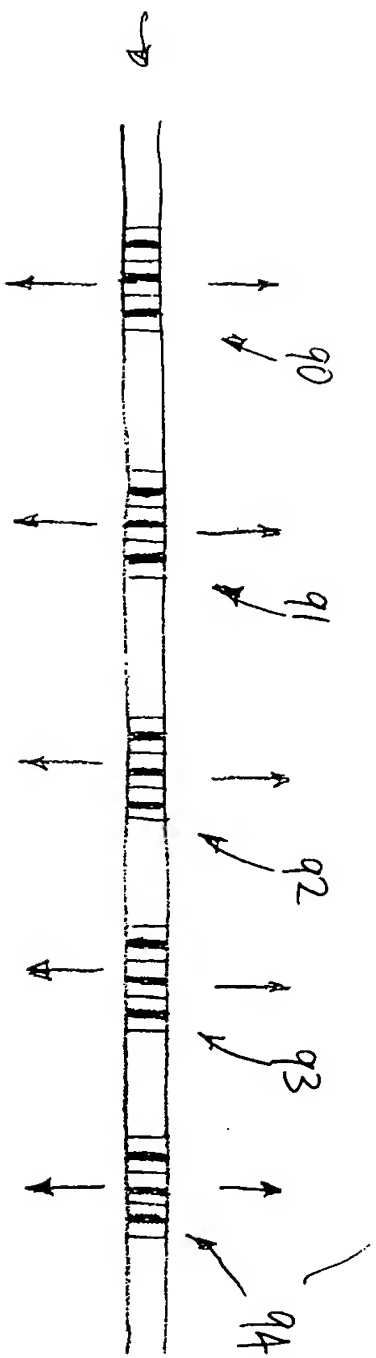


Fig. 14.

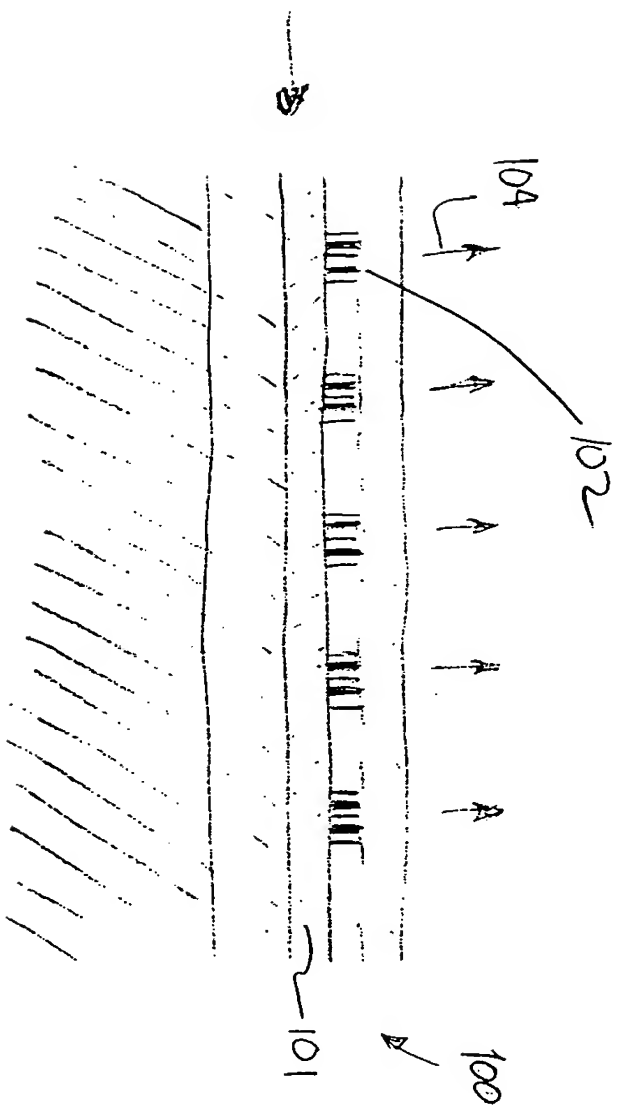
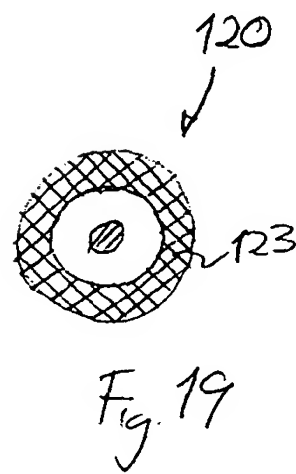
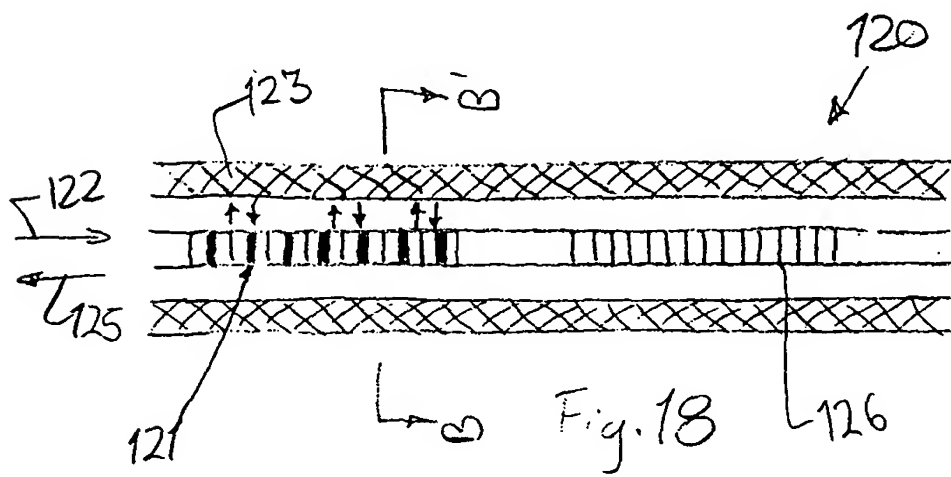
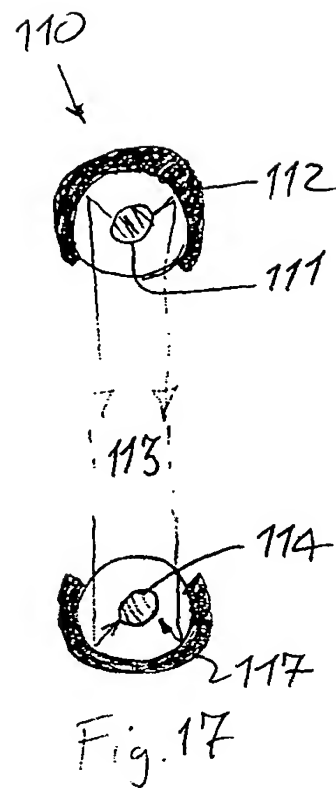
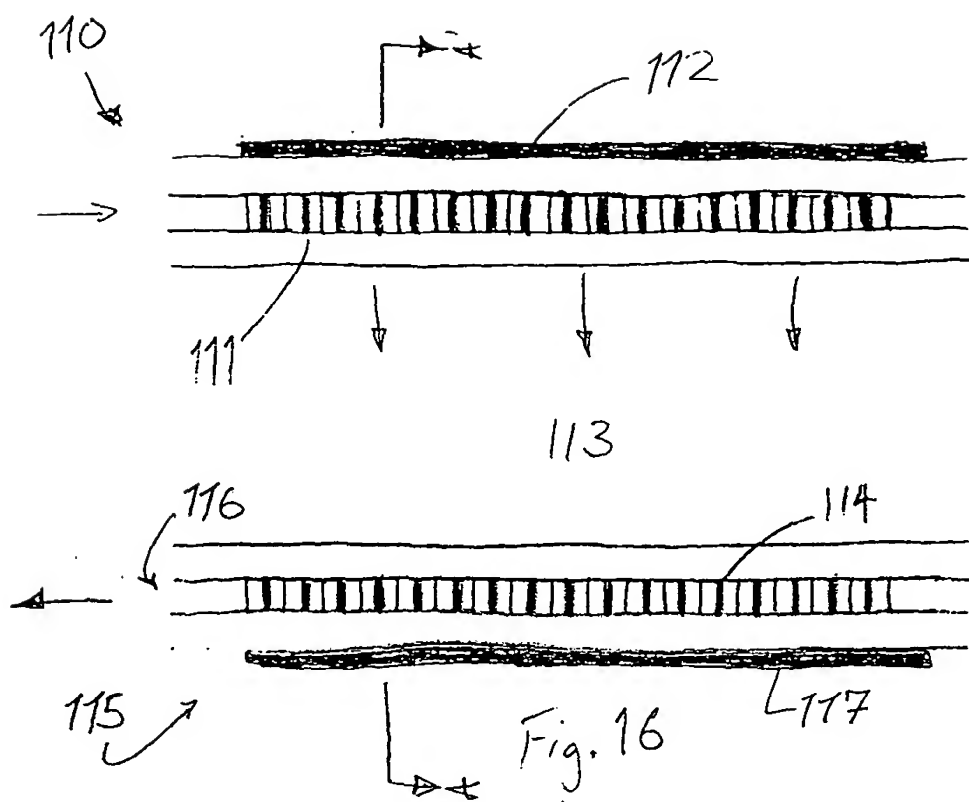


Fig. 15.



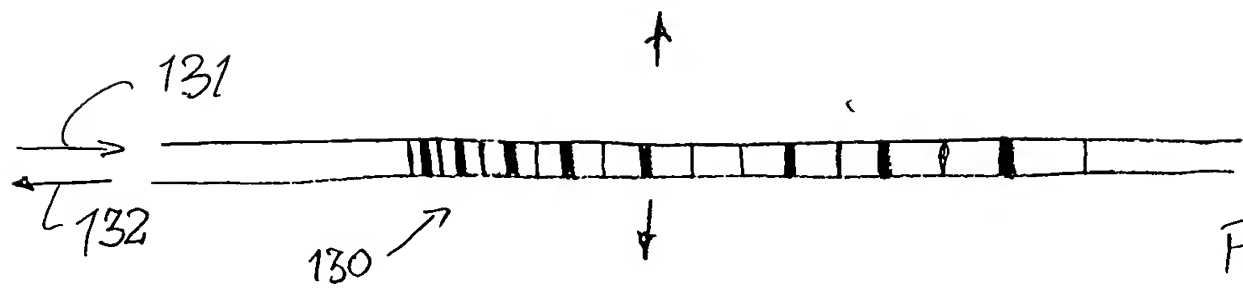


Fig. 20

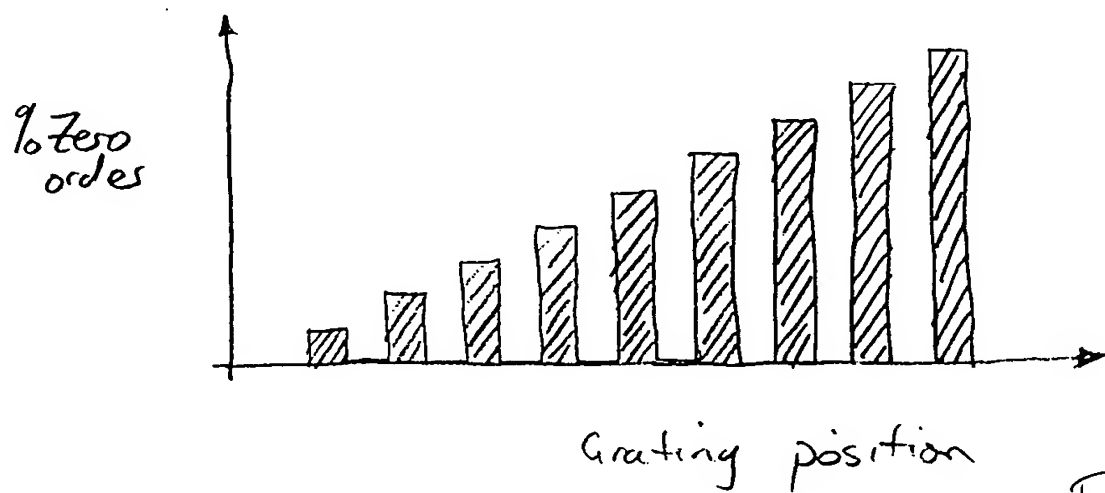


Fig. 21

